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Tribological Characteristics of MoS_2 Coatings in High Vacuum

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Abstract : The friction and wear behavior of MoS_2 coatings was investigated using a pin and disk type tester. The experiment was conducted with silicon nitride as the pin material and MoS_2-on-bearing steel as the disk material under different operating conditions that included linear sliding velocities within a range of 2266 mm/sec, normal loads varying from 9.829.4 N, corresponding to maximum contact pressures of 1.782.83 Gpa, and high vacuum, medium vacuum, and ambient air atmospheric conditions. The results showed a low friction coefficient for the coating in a high vacuum, plus the friction coefficient and wear volume increased with an increased normal load. Furthermore, under high load conditions, the friction coefficient and wear volume also increased with an increased sliding velocity.

Key words : MoS_2, high vacuum, friction coefficient, pin and disk type

Introduction

Space applications have to withstand pressures ranging from the atmosphere to an ultra-high vacuum, plus a wide range of temperatures from -100℃ to +150℃ and dusty conditions etc. [1-2].

Under these conditions, oils and other liquid lubricants become impractical because of the increased viscosity effect at low temperatures, and in a vacuum their condensed vapors end up contaminating instrumental components.

As a result, research on solid lubricants (e.g., MoS_2, WS_2, PTFE, graphite, Ag, In) has increased and become more important [3-9]. Among these solid lubricants, Molybdenum disulfide (MoS_2) coatings exhibit very favorable tribological properties under vacuum conditions with a high load carrying capacity and ultra-low friction. Therefore, it is currently being used in precision instruments, including satellite bearings.
Kato *et al.* [5] showed that the frictional pair of a ceramic (Si_3N_4) pin and bearing steel disk produces the smallest friction coefficient.

Accordingly, the main purpose of this study is to conduct experimental measurements in order to understand the friction mechanisms of a MoS_2-bonded bearing steel disk and ceramic pin in controlled atmospheres.

Experimental Apparatus and Procedure

Fig. 1 shows a schematic diagram of the vacuum tester, which was designed and manufactured for this experiment. The normal load was supplied by a dead weight, and the friction force was measured using a load cell.

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In this study, the specimens were MoS_2-bonded AISI 52100 steel as the disk material and silicon nitride as the pin material (2.5mm curvature radius).

The properties of the specimens are shown in Table 1.

The experiment was performed under various conditions:

- Atmosphere [Pa]: high vacuum(10^{-4}), medium vacuum (10^{-1}), and ambient air
- Normal load [N]: 9.8, 19.6, 29.4
  (Maximum contact pressure of 1.8~2.8Gpa)
- Linear sliding velocity [mm/sec]: 22, 44, 66 (rotation velocity [rpm]: 30, 60, 90)

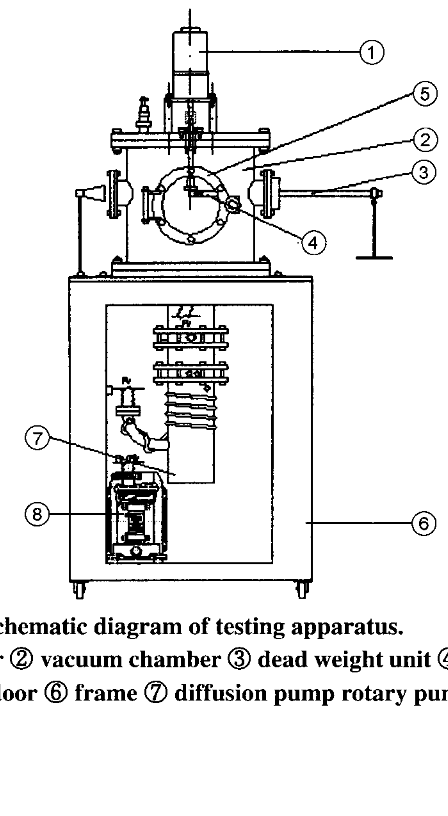


Fig. 1. Schematic diagram of testing apparatus.
① motor ② vacuum chamber ③ dead weight unit ④ load cell unit ⑤ door ⑥ frame ⑦ diffusion pump rotary pump.

Table 1. Properties of specimens.

	AISI 52100	Si_3N_4
Vickers Hardness, kgf/mm^2	650	1700
Tensile strength, MPa	1379	524
Elastic modulus, GPa	200	320
Density, $\times 10^3 kg/m^3$	6.37	3.04
Thermal cond., W/mK	43.25	30
Thermal expans., $\times 10^{-6}/^{\circ}C$	12.4	3.3

Results and Discussion

Frictional characteristics of MoS_2 coatings

A low friction coefficient was exhibited during the initial state, however, it increased relative to the repeating sliding motions. Regardless of the contact conditions, the friction coefficient increased because, initially, the surface asperity was stable during the running-in process, however, the continuing sliding motion reduced the surface asperity and oxide layer, the surface asperity then left its stable state, and the resulting coating failure made the coefficient increase.

Fig. 2 shows the friction characteristics relative to the atmospheric conditions under a normal load of 9.8 N and sliding velocity of 22 mm/sec. In the case of a high vacuum the average friction coefficient was distinctively low compared with that of ambient air conditions, plus the steady state was notably long. The average friction coefficient was between 0.02 and 0.05 in a high vacuum, 0.1~0.15 in ambient air, and 0.08~0.1 in a medium vacuum. Therefore, according to these results, the friction coefficient of the MoS_2 coatings proved to be extremely low in a high vacuum. The main causes of the different friction characteristics related to the various atmospheric conditions were oxygen and water vapor. It has been previously reported that oxygen and water vapor change the nature of a MoS_2 crystal and cause a disorder in the atomic structure in ambient air [6]. Generally, the friction coefficient of a coating decreases with an increased normal load and its lifetime is cut drastically [9]. In particular, this phenomenon can be observed in the case of a low normal load or low contact pressure. However, this did not occur in this study because the maximum contact pressure of the experiment was extremely high at 1.8~2.8 Gpa.

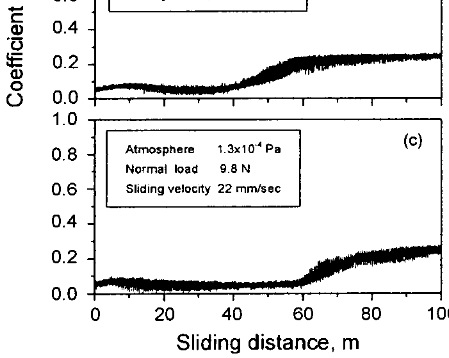


Fig. 2. Variation of coefficient as a function of sliding distance.

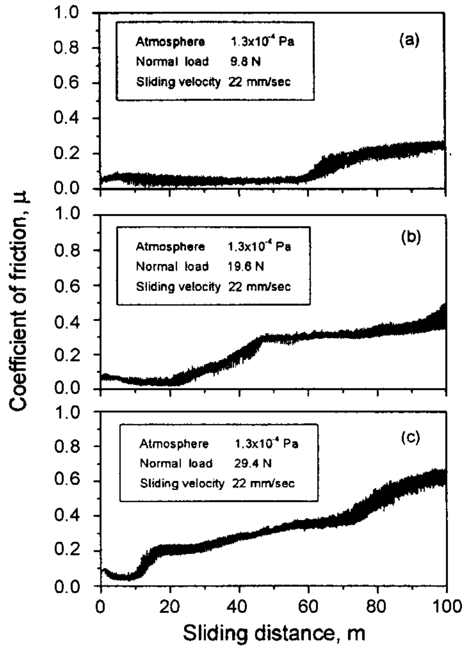


Fig. 3. Variation of coefficient as a function of sliding distance.

Fig. 3 shows the friction characteristics with different normal loads of 9.8 N, 19.6 N, and 29.4 N under a high vacuum and sliding velocity of 22 mm/sec. The sliding distance required to maintain a steady state under a normal load of 9.8 N was much longer than that under 29.4 N due to the plowing phenomenon, which caused the high friction

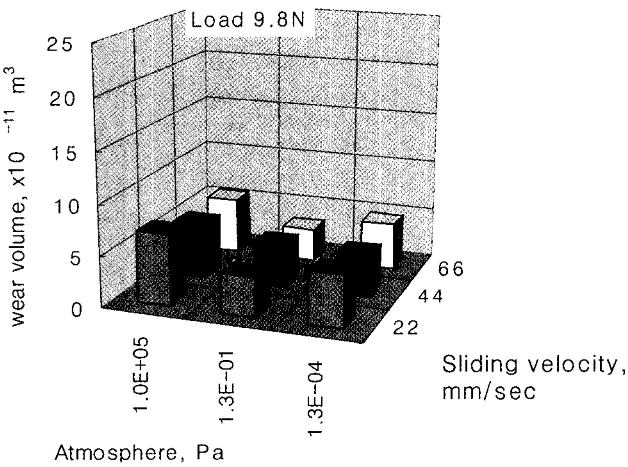


Fig. 4. Wear volume of MoS_2-coated disk.

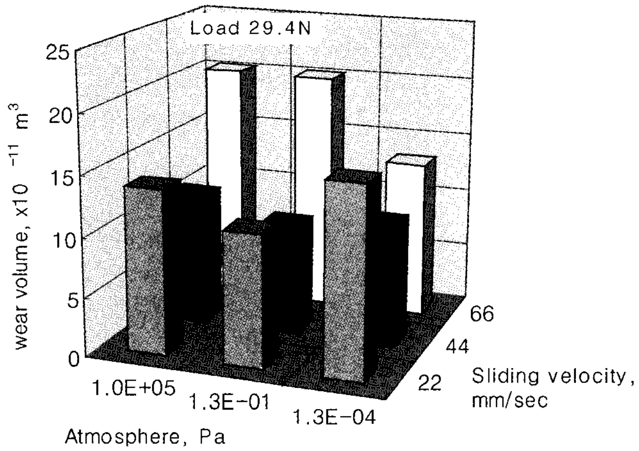
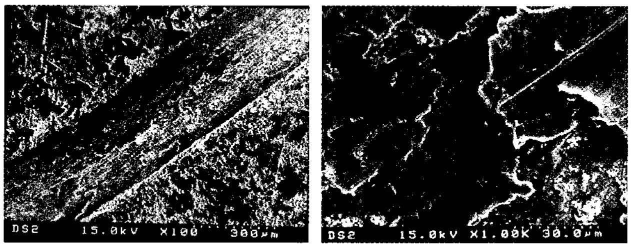


Fig. 5. Wear volume of MoS_2-coated disk.



(a) x 100 (b) x 1000

Fig. 6. SEM photograph of worn surface of MoS_2 coating (normal load: 9.8 N, sliding velocity: 44 mm/sec, atmosphere: high vacuum).

coefficient of the MoS_2 coatings. In addition, this was particularly noticeable with a high sliding velocity.

Wear characteristics of MoS_2 coatings

Figs. 4 and 5 show the wear volume relative to the experimental conditions.

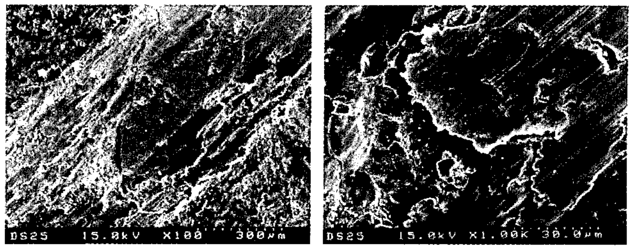
In the case of a high vacuum, the wear volume was low compared with that of ambient air conditions, which was due to the low friction coefficient in a high vacuum. In particular, the wear volume increased with an increase in the sliding velocity and a high load.

Microscopic observations of worn surface

Figs. 6~8 show SEM photographs of the worn surfaces. The case of a normal load of 9.8 N in Fig. 6 shows a relatively less worn surface compared with the worn surface with a normal load of 29.4 N, as shown in Fig. 7. This was particularly noticeable with a higher sliding velocity, as shown in Fig. 8. This was caused by severe plastic deformation as the normal load increased and thermal damage as the sliding velocity increased.

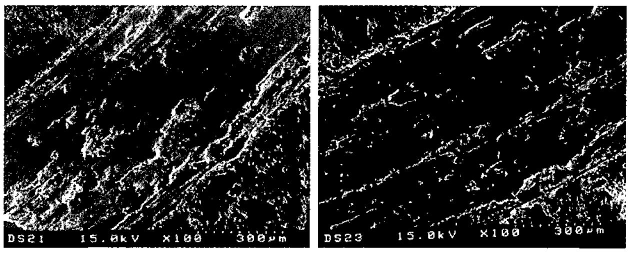
Conclusions

This paper conducted experimental measurements to understand the friction mechanisms of MoS_2 coatings in controlled atmospheres.



(a) x 100 (b) x 1000

Fig. 7. SEM photograph of worn surface of MoS_2 coating (normal load: 29.4 N, sliding velocity: 44 mm/sec, atmosphere: high vacuum).



(a) x 100 (b) x 1000

Fig. 8. SEM photograph of worn surface of MoS_2 coating (normal load: 29.4 N, atmosphere: high vacuum).

The main results obtained from the experiment are as follows;

1. The friction coefficient of the MoS_2 coatings proved to be low in a high vacuum. (μ: 0.02~0.05)
2. The friction coefficient of the MoS_2 coatings in ambient air was between 0.1 and 0.15 because of a change in the nature of the MoS_2 crystals caused by oxygen and water vapor.
3. Under high contact pressure, the friction coefficient and wear volume of the MoS_2 coatings increased with an increased normal load.
4. Under high load conditions, the friction coefficient and wear volume of the MoS_2 coatings increased with an increased sliding velocity.

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